22 CHANGES OF PHYSICAL STATE

Text Reference
Section 13.4

Time Required
45 minutes

Objectives

- Observe the behavior of lauric acid during melting and freezing.
- Prepare a graph of the heating and cooling curves for lauric acid.
- Interpret the freezing and melting point of lauric acid.
- Hypothesize about what happens to the energy that is put into or removed from lauric acid during melting and freezing.

Advance Preparation
The tubes and wire loops can be prepared ahead of time (or by the first hour's students) and used by subsequent classes.

The lab can be simplified if tubes of lauric acid are warmed to 60°C before class so that students can use the first part of the period to obtain data for the cooling curve.

Lauric acid, $CH_3(CH_2)_{10}COOH$, has a molar mass of 200.3 g/mol and a density of 0.87 g/cm^3. This compound melts at 44.0°C and boils at 131.0°C.

PURPOSE

To investigate the melting and freezing behavior of a compound.

BACKGROUND

If you have ever cooled a glass of water with ice cubes and watched water vapor condense on the outside of the glass, you know water can exist in distinct physical states—the solid state (ice), the liquid state (water), and the gaseous state (water vapor). In any pure substance, changes of physical state occur at constant, discrete temperatures that are uniquely characteristic of the substance. Changes in physical state include solids melting, liquids freezing or boiling, and gases condensing.

In this experiment, you will closely examine what happens when a substance undergoes a change in physical state. Specifically, you will investigate the melting and freezing behavior of a sample of an organic compound called lauric acid, $CH_3(CH_2)_{10}COOH$. You are chiefly concerned with two questions. First, does liquid lauric acid begin to freeze at the same temperature that solid lauric acid begins to melt? Second, what happens to the temperature of the lauric acid between the time freezing or melting begins and the time it is complete? You will also consider what happens to the energy that is put into or removed from the lauric acid system during melting or freezing.

MATERIALS (PER PAIR)

safety goggles	2 ring stands
2 400-mL beakers	2 ring supports
2 thermometers	pliers
rubber stopper	beaker tongs or insulated glove
large test tube	timer with second hand
2 wire gauzes	tap water
2 utility clamps	lauric acid, $CH_3(CH_2)_{10}COOH$
2 gas burners	20-cm copper wire, Cu

SAFETY FIRST!

In this lab, observe all precautions, especially the ones listed below. If you see a safety icon beside a step in the Procedure, refer to the list below for its meaning.

Caution: Wear your safety goggles. (All steps.)

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Caution: Exercise care when working with hot water baths to prevent a thermal burn. Do not touch the beaker containing hot water with your bare hands. (Steps 2, 4, 5.)

Caution: Never use a thermometer as a stirrer. (Steps 3, 5, 6.)

Note: Return or dispose of all materials according to the instructions of your teacher. (Step 7.)

PROCEDURE

As you perform the experiment, record your data in Data Table 1.

Part A. The Change From Liquid to Solid

1. Heat about 250 mL of water in a 400-mL beaker to 30°C. Separately, heat 250 mL of water in another 400-mL beaker to 60°C.
2. Use a utility clamp to support a large test tube containing approximately 20 g of acid in the hot (60°C) water, as shown in Figure 22.1. Make sure that the lauric acid is totally beneath the water in the beaker and that the test tube does not touch the bottom of the beaker.

CAUTION: Teach students the proper technique for inserting a thermometer in a rubber stopper. See p. 16.

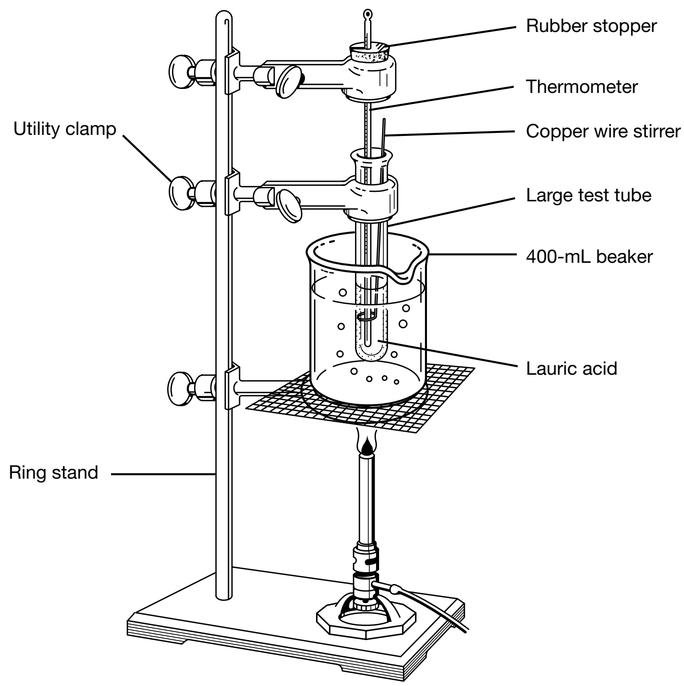

Figure 22.1

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3. While the sample is heating, use the pliers to construct a stirrer from a piece of stiff copper wire, as shown in Figure 22.2. When the crystals have melted, slip the loop of the wire stirrer around a thermometer fitted with a rubber stopper. Referring to Figure 22.1, place the stirrer-thermometer assembly in the test tube so that the thermometer bulb is at the center of the molten lauric acid and the stirrer moves easily up and down. The bulb of the thermometer should not touch the bottom of the test tube. Make certain that the markings on the thermometer can be easily read.

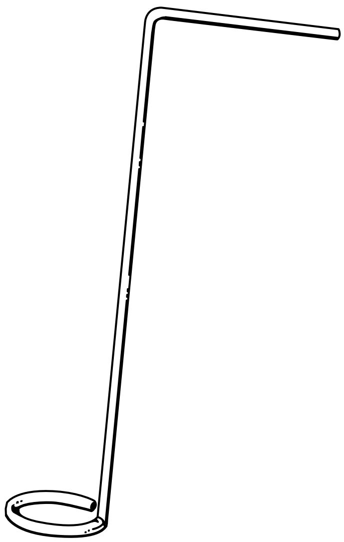

Figure 22.2

4. Carefully replace the beaker containing the 60°C water with the beaker containing the 30°C water. Do this by removing the gas burner and lowering the ring support while holding the beaker with tongs or insulated gloves. Return the ring support to its previous position.

5. Gently stir the lauric acid. When its temperature has fallen to about 55°C, take a temperature reading every 30 seconds. Record the temperature to the nearest 0.1°C. Continue stirring the lauric acid and recording temperature readings until the temperature of the material has fallen to 40°C or lower. (**Note:** When most of the lauric acid has solidified, you will no longer be able to stir the contents. Continue taking temperature readings during this period.)

Part B. The Change From Solid to Liquid

6. Replace the beaker containing 30°C water with one that contains water at approximately 55°C. Begin to collect temperature data immediately. Record temperature measurements of the test-tube contents every 30 seconds until the lauric acid is completely melted. Begin stirring as soon as you are able to move the copper stirrer freely. **CAUTION:** *Do not force the stirrer.*

Use the following disposal method for chemical waste.

Disposal 1: lauric acid.

7. Carefully disassemble the apparatus and dispose of the lauric acid as directed by your teacher.

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OBSERVATIONS

DATA TABLE 1: HEATING AND COOLING DATA

Part A		Part B	
Time (min)	Temperature (°C)	Time (min)	Temperature (°C)
0	55.0	0	30.0
0.5	52.6	0.5	33.2
1.0	49.5	1.0	35.5
1.5	45.5	1.5	37.5
2.0	44.3	2.0	39.0
2.5	44.1	2.5	41.0
3.0	44.0	3.0	42.0
3.5	44.0	3.5	42.6
4.0	44.0	4.0	43.0
4.5	44.0	4.5	43.3
5.0	44.0	5.0	43.6
5.5	44.0	5.5	43.7
6.0	44.0	6.0	43.8
6.5	44.0	6.5	44.0
7.0	44.0	7.0	44.0
7.5	43.7	7.5	44.1
8.0	43.5	8.0	44.2
8.5	43.3	8.5	44.5
9.0	43.0	9.0	45.2
9.5	42.6	9.5	46.0
10.0	42.3	10.0	47.5
10.5	41.9	10.5	49.0
11.0	41.5	11.0	51.4

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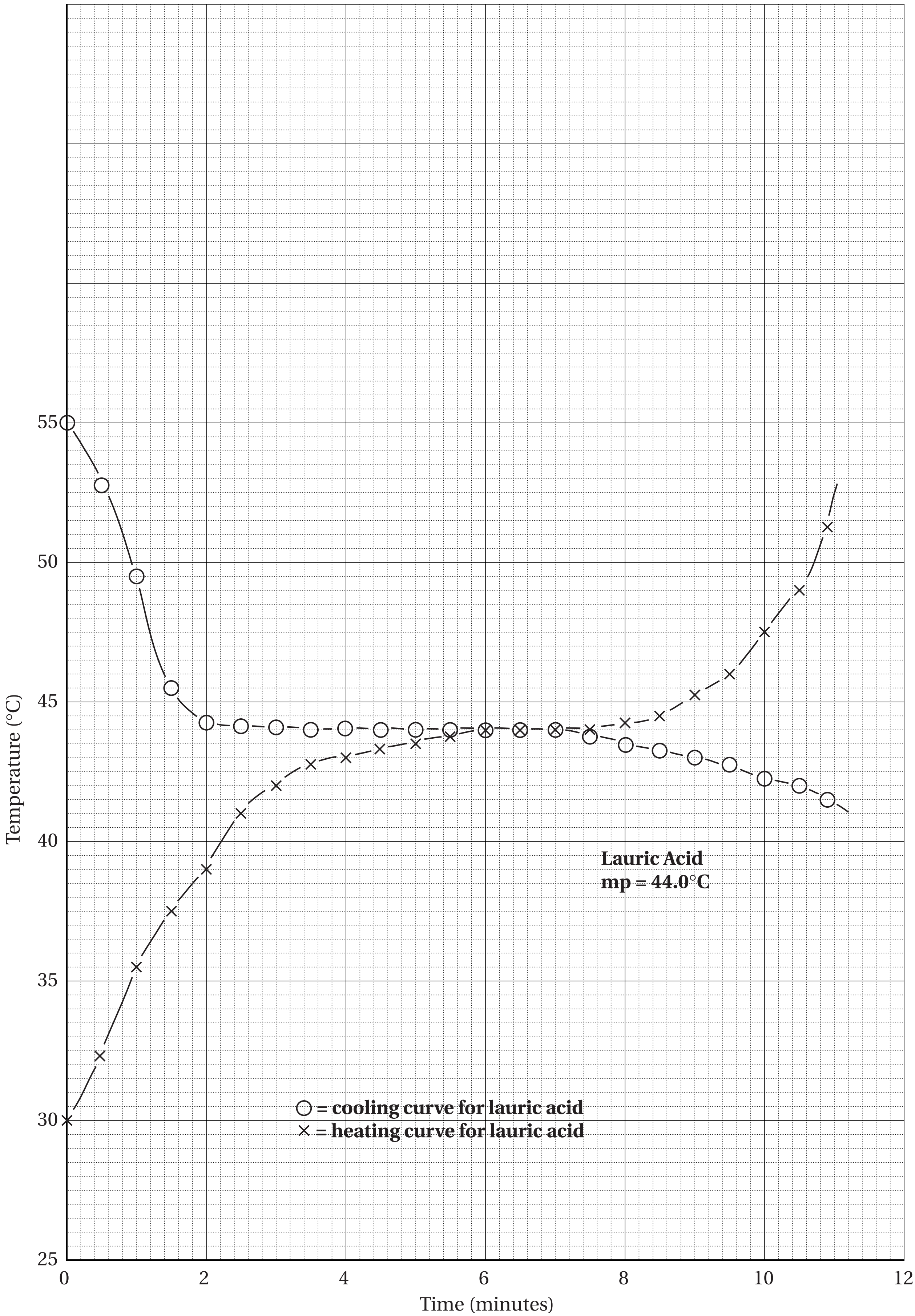

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ANALYSES AND CONCLUSIONS

1. Construct a graph of your data from Part A. Plot temperature versus time. Draw a smooth curve through the points.
2. Plot the data from Part B on the same graph and draw a smooth curve.
3. Does the temperature of a substance vary while it is melting or freezing? Explain.

   The temperature tends to remain constant.

4. Using data from Part A, determine the freezing point of lauric acid.

   44.0°C

5. Using data from Part B, determine the melting point of lauric acid.

   44.0°C

6. Does lauric acid melt and freeze at the same temperature?

   Yes, within the limits of experimental error (theoretical melting point is 44.0°C).

7. Explain the shape of the curves in terms of the energy changes that are occurring in the sample as it heats up and melts and as it cools down and freezes.

   As lauric acid is heated, its temperature increases gradually until its melting point is reached. During the melting process, energy is absorbed by the solid, although the temperature remains constant. The energy added during this stage is used to separate the closely packed molecules of the solid. As these molecules are separated from each other, their potential energy increases. There is, however, no increase in average kinetic energy—and therefore no increase in temperature—until all the molecules of the solid have been separated to the intermolecular distances characteristic of the liquid state. In other words, there is no increase in temperature until the entire sample has melted. Once all the solid has melted, heating increases the kinetic energy of the liquid, and the temperature is observed to increase gradually.

8. Explain how an increase in the amount of lauric acid used would affect the shape of the curves.

   Increasing the amount of lauric acid would increase the total time required for each phase change and would, therefore, cause the horizontal sections of the graph to be longer. There would be no effect on the melting point.

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9. Explain in your own words what is going on at the molecular level as liquid lauric acid cools and freezes.

The cooling curve of lauric acid is the opposite of its heating curve. As the liquid is cooled, the kinetic energy of the lauric acid molecules gradually decreases until the freezing point is reached. At the freezing point, the liquid begins to solidify. At this point, the average kinetic energy of the molecules remains constant while their potential energy decreases as the molecules are pulled closer together by attractive intermolecular forces. Energy is still being removed from the system, but all in the form of potential energy, not kinetic energy. For this reason, no temperature change is observed. Once all the molecules have attained the close intermolecular distances characteristic of the solid state—that is, when all the liquid has solidified—kinetic energy can again be removed from the system. Continued cooling of the solid after the phase change is complete will cause a decrease in the average kinetic energy of the molecules in the solid, and the temperature of the solid will be observed to decrease.

GOING FURTHER

Develop a Hypothesis

Based on what you have learned about the melting behavior of lauric acid, develop a hypothesis about how the melting behavior of lauric acid would change if an impurity was introduced into the sample.

Hypotheses will vary. In general, the melting point of a compound is depressed (decreases) when impurities are present in a sample of the compound. The actual change in the freezing point will depend on the amount of impurities in the sample. Chemists often use melting points to evaluate the purity of a sample.

Do Research

If resources are available, read textbooks or articles about the melting behaviors of solids that will support or disprove your hypothesis.